MARINER 9 ULTRAVIOLET SPECTROMETER EXPERIMENT:

Afternoon Terminator Observations of Mars

J. M. AJELLO

Physics Section
Jet Propulsion Laboratory
Pasadena, California 91109

C. W. HORD

C. A. BARTH

A. I. STEWART
Department of Astro-Geophysics
Laboratory for Atmospheric and Space Physics
University of Colorado, Boulder, Colorado 80302

and

A. L. LANE

Physics Section
Jet Propulsion Laboratory
Pasadena, California 91109

ABSTRACT

Analysis of the Mariner 9 ultraviolet spectrometer twilight data of Mars measured at 3050 Å indicates the presence of two characteristic types of atmospheric scattering properties. Measurements in the mid-latitudes, from 15° South to 50° North, require a scattering layer at an altitude of 60 to 90 km in order to explain the intensity variation with solar depression angle. A scattering layer of optical thickness 0.005 combined with a homogeneous lower atmosphere having a nominal 10 km scale height will explain the mid-latitude measurements. North of 50° latitude the terminator intensity is enhanced and decreases rapidly with increasing solar depression angle. The terminator scattering at northern latitudes can be explained by a homogeneous scattering medium with an optical thickness ≥ 0.1, a single scattering albedo of 0.3 to 0.4, and an effective scale height of 6 to 8 km. Atmospheric water ice may account for both the mid-latitude scattering layer and enhanced scattering in the northern latitude lower atmosphere.

INTRODUCTION

During the Mariner 9 mission there were approximately 200 observations of the Martian evening twilight. In these observations the motion of the Mariner spacecraft swept the field of view of the Mariner 9 ultraviolet spectrometer across the terminator. During these terminator crossings, the ultraviolet spectrometer obtained a complete spectrum every three seconds covering the wavelength interval from 1100 - 3400 Å at 15 Å resolution. For this initial analysis of ultraviolet spectrometer terminator data, the variation in intensity observed in a 100 Å wavelength band centered at 3050 Å is considered. Data points shown in subsequent figures are plotted every 9 seconds which is adequate to show the gross variations described here. Some previous results from other phases of the Mariner 9 ultraviolet experiment have been described by Barth _et al._ (1972a, 1972b); Hord _et al._ (1972); Lane _et al._ (1973); and Stewart _et al._ (1972).

During the mission, the geographical point of the terminator crossing moved, in general, northward with the advance of spring in the north. At the same time, the lower atmosphere began to clear from the dusty conditions of the early mission.

The modeling and interpretation of twilight data have been described in detail (Rozenburg, 1966). Determination of altitude distributions for absorbing and scattering constituents from ground-based observations of the Earth's twilight have been carried out by a number of authors (e.g., Volz and Goody, 1962; Hunten, 1954). Terminator observations provide a measure of atmospheric properties down to an altitude where the incident extinction optical path to the scatterers, along the instrument's line of sight, becomes greater than one.

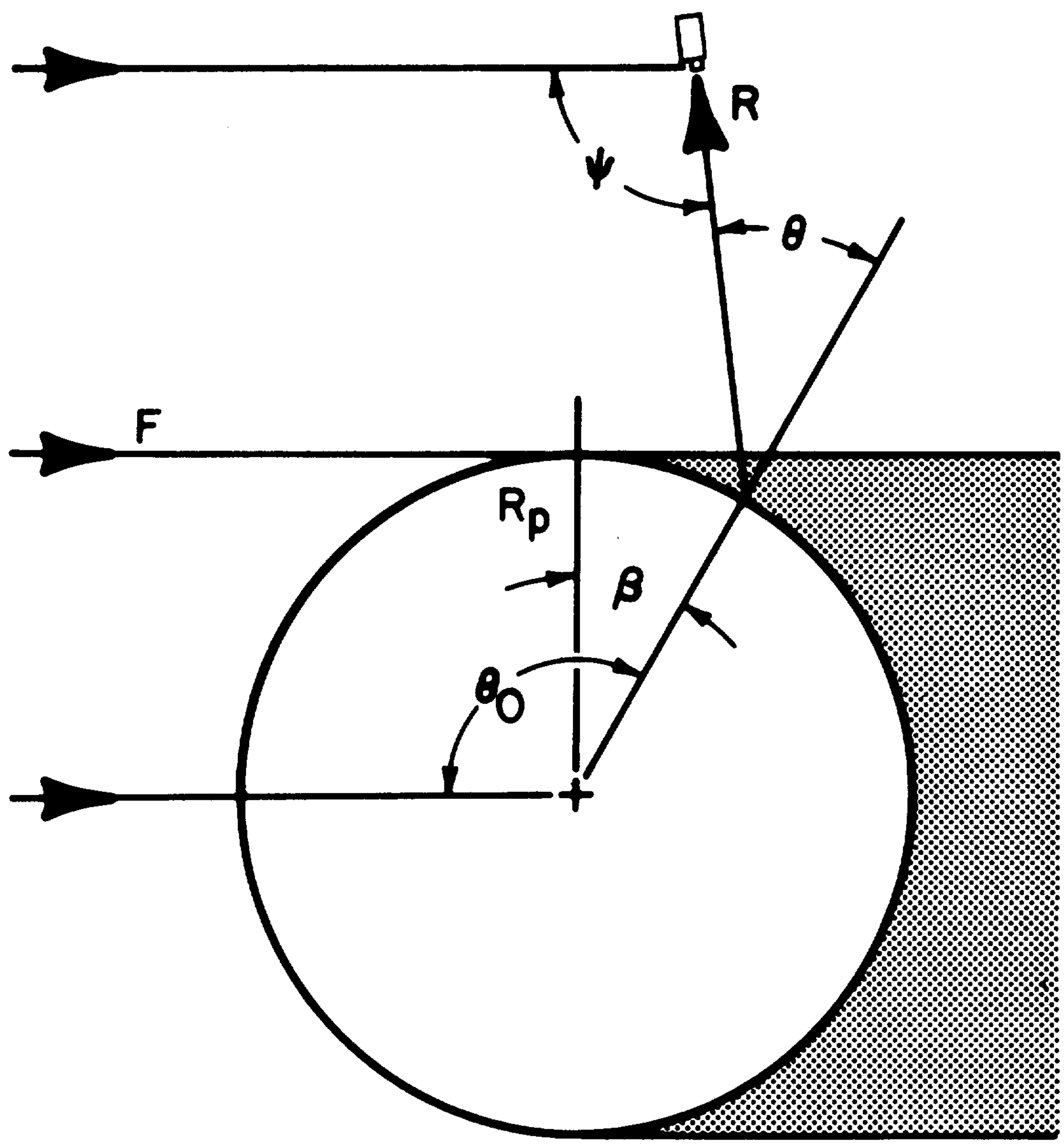
TERMINATOR MODEL

The Mars terminator as observed at 3050 Å is quite dim compared with the intensities expected from a purely scattering, optically thick model, indicating that multiple scattering is not important. The lack of a multiple scattering correction may affect the interpretation for large solar depressions angles, $\beta > 5°$. None of the interpretations given here depend critically upon data obtained at large solar depression angles. Refraction effects are also neglected as the optical depths are not large.

The geometry of observation is shown in Figure 1, where θ is the emission angle, θ_0 is the solar incidence angle, β is the solar depression angle, R_p is equal to the radius of Mars, and ψ is equal to the supplement of the scattering angle. It is convenient to use the quantities $\mu = \cos\theta$ and $\mu_0 = \cos\theta_0$, where $\beta = |\mu_0|$ for small β.

In this discussion, ultraviolet spectrometer twilight measurements will be interpreted in terms of two simple models. For the first model, the atmosphere is assumed to be homogeneous and to have a constant scale height. Under these conditions, three independent parameters

Figure 1 Geometry of terminator observations. The solar flux, F, is scattered by the atmosphere of Mars, and the resulting reflectivity, R, is measured by the Mariner 9 ultraviolet spectrometer.



R
ψ
θ
F
R_p
β
θ_O

which describe the atmosphere are the scale height, H; the total vertical extinction optical depth, τ; and the effective single scattering albedo, ϖ_0. The second model, in addition to the homogeneous lower atmosphere of the first model, has a pure scattering layer. The parameters necessary to specify the scattering layer are Z, the height of the bottom of the scattering layer above the level where total slant incident optical path is one; h, the thickness of the layer in kilometers; and τ_L, the scattering optical thickness.

For the homogeneous model, the predicted reflectivity is

$$R = \frac{p(\psi)\varpi_0}{4\mu M} \exp(-x\mu_0{}^2/2)[1 - \exp(-\tau M)] \qquad (1)$$

where $p(\psi)$ is the phase function of the scatterers, M is an air mass factor, and $x = R_p/H$. The value of R from equation (1) is to be compared with the measured reflectivity, which is intensity multiplied by π and divided by the solar flux. The air mass, correct to 0.1 per cent, is given by:

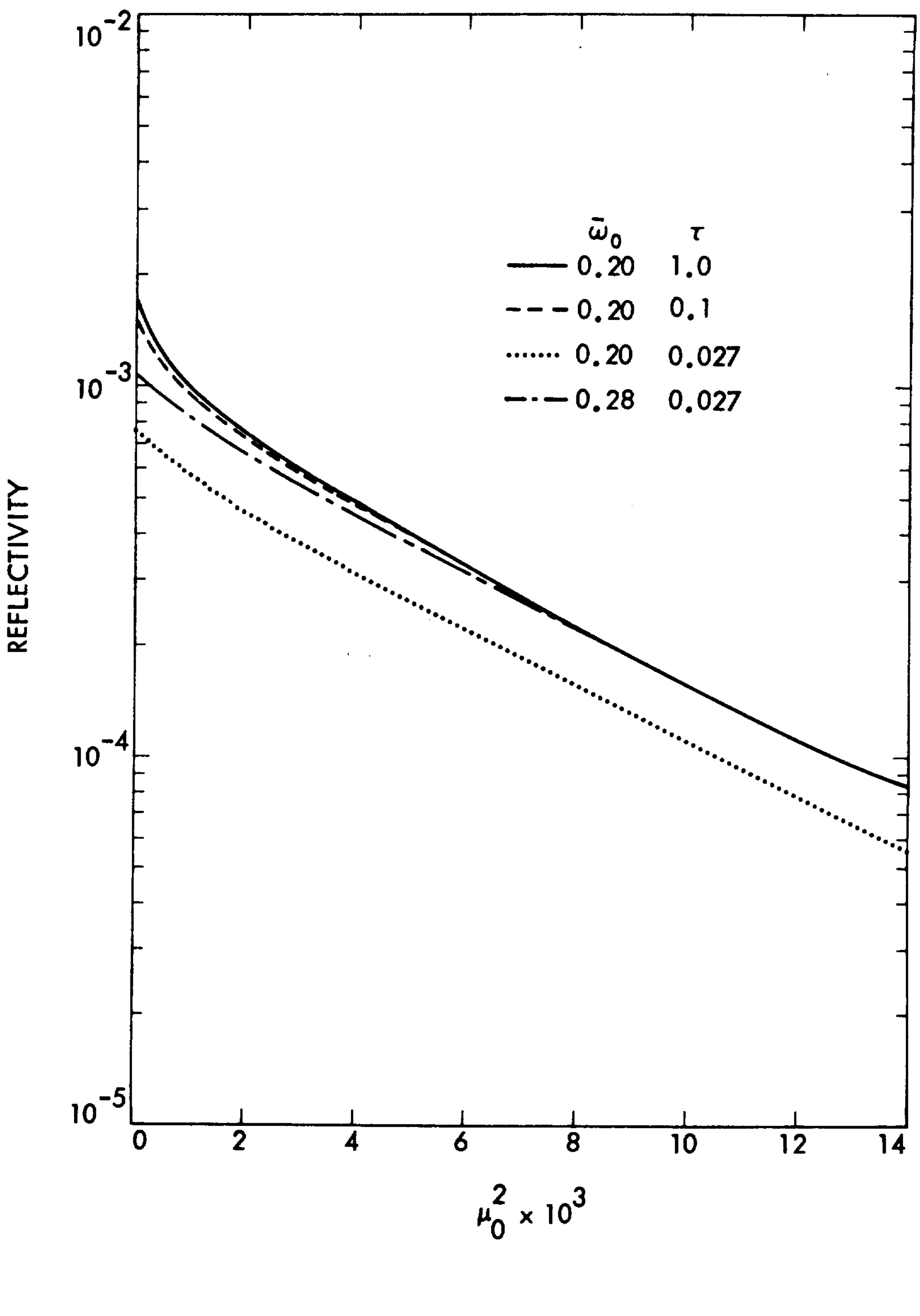
$$M = (\pi x/2)^{\frac{1}{2}}[1 + \mathrm{erf}(x\mu_0{}^2/2)^{\frac{1}{2}}] + (1/\mu)\ \exp(-x\mu_0{}^2/2) \qquad (2)$$

and is defined as the number of vertical optical depths traversed by a 3050 Å photon along a path tangent to the surface and singly scattered into the spectrometer field of view. The error function is represented by erf. For a typical Mars scale height of 10 km, M varies from 23 for zero solar depression angle to 46 as the solar depression angle increases. When the maximum optical path τM becomes greater than one, the predicted reflectivity is insensitive to extinction optical depth, τ, and, therefore, to the absolute altitude measured from the surface of Mars. In this case, the predicted reflectivity is completely specified by ϖ_0 and H. The dominant dependence of R is in the factor $\exp(-x\mu_0{}^2/2)$, which represents the decrease in intensity as the shadow height $(R_p\mu_0{}^2/2)$ increases with increasing solar depression angle. Figure 2 shows the homogeneous terminator model for different values of ϖ_0 and τ for an atmosphere having a 10 km scale height. For pure molecular scattering from a 5 mb CO_2 atmosphere, $\tau = 0.027$ at 3050 Å. The coincidence of these models as the solar depression angle increases is a consequence of all models having the same scale height. The slope of reflectivity as a function of the square of solar depression angle, $\beta^2 \approx \mu_0{}^2$, on a semi-logrithmic scale is a measure of scale height.

The effect of adding an additional pure absorption component with a scale height, H_A, different from that of the homogeneous part is shown in Figure 3. Values of ϖ_0 are given at an extinction optical depth of one measured from the top of the atmosphere. This model, which corresponds to absorbing dust mixed in decreasing relative amount at higher altitudes, is not found to materially improve agreement with observation.

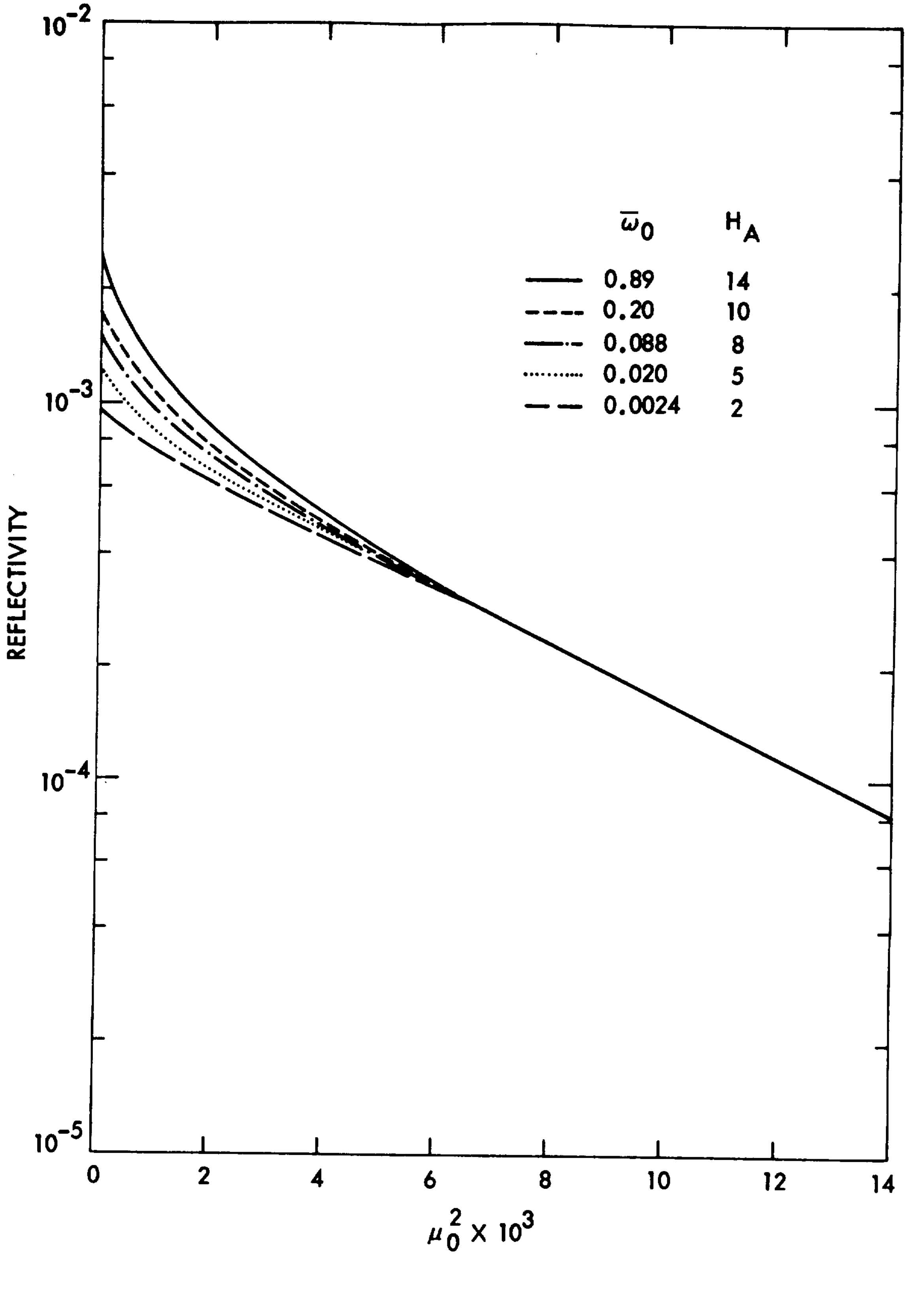
Twilight observations made in the mid-latitudes show a relatively slow decrease in reflectivity with solar depression angle. If these terminator crossings are interpreted in terms of a homogeneous model, the apparent scale heights are of the order of 20 or 30 km which are physically unreasonable values. A scale height of 10 km corresponds to a terminator temperature of 190° K. In order to explain these large apparent scale heights with a spherically symmetric atmosphere, it is necessary for a high altitude scattering layer to exist.

Figure 2 Model twilight reflectivity for a homogeneous atmosphere with H = 10 km, for different values of the single scattering albedo, ϖ_0, and vertical extinction optical thickness τ. The horizontal axis is μ_0^2, which is equal to the square of the solar depression angle. Multiplying the abscissa value of $\mu_0^2 \times 10^3$ by 1.7 gives the geometrical shadow height in kilometers. Vertical viewing is assumed, i.e., $\mu = 1$.



$\bar{\omega}_0$ τ
0.20 1.0
0.20 0.1
0.20 0.027
0.28 0.027
REFLECTIVITY
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0 2 4 6 8 10 12 14
$\mu_0^2 \times 10^3$

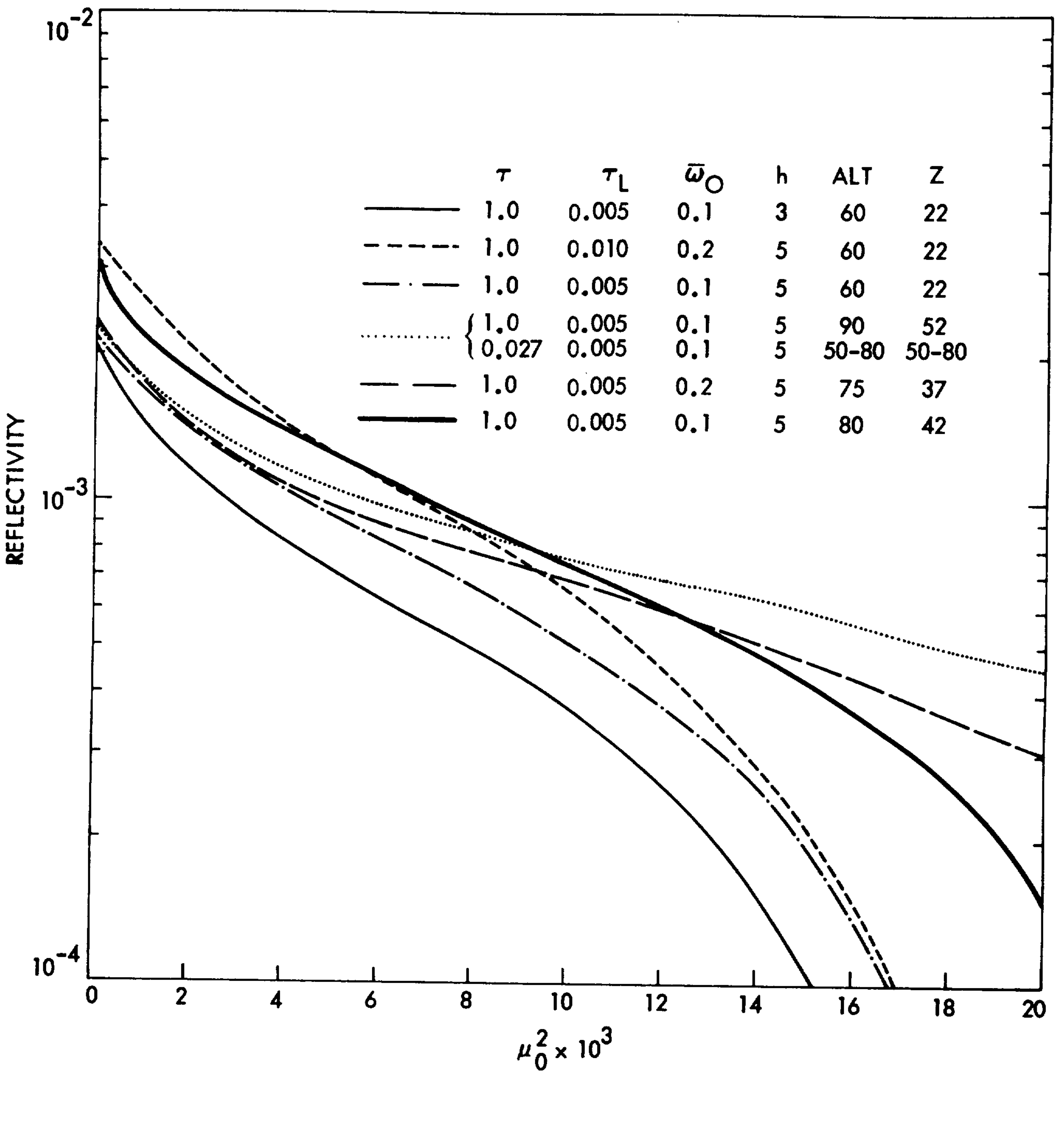
Figure 3 Model twilight reflectivity for a two-component atmosphere. The vertical optical depth is 1; the scale height is 10 km.



10^{-2}
10^{-3}
10^{-4}
10^{-5}
REFLECTIVITY
0
2
4
6
8
10
12
14
$\mu_0^2 \times 10^3$
$\overline{\omega}_0$
H_A
0.89 14
0.20 10
0.088 8
0.020 5
0.0024 2

Figure 4 shows model terminator reflectivities for several values of the homogeneous lower atmosphere parameters, τ and ϖ_0, and varying values of the scattering layer parameters, τ_L, h, and Z. A scale height of 10 km is assumed for all of the lower atmosphere models and $p(\psi)$ is taken to be one for both the lower atmosphere and the scattering layer. For the scattering layer, $\varpi_0 = 1$. The scattering layer model is of the right shape and magnitude to reproduce the terminator data, if $\tau_L \approx 0.005$. For $\tau_L > 0.02$, the apparent scale height of the predicted reflectivity is too small, i.e., the fall off of the predicted intensity with $\mu_0{}^2$ is too steep. This is because most of the direct radiation is scattered out of the incident solar beam before reaching a large value of $\mu_0{}^2$. On the other hand, if $\tau_L < 0.002$, the predicted signal from the layer is too small to reproduce the measured data. Values of the scattering layer optical thickness, τ_L, tend to be upper limits, as effects of multiple scattering and refraction both tend to increase the brightness beyond the terminator and cause the apparent scale height to be larger than predicted by the simple model used here.

Figure 4 Model twilight reflectivity for a scattering layer above a homogeneous lower atmosphere. The altitude of the scattering layer above the surface of the planet is designated by ALT.



REFLECTIVITY
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
10
12
14
16
18
20
$\mu_0^2 \times 10^3$
τ τ_L $\bar{\omega}_0$ h ALT Z
1.0 0.005 0.1 3 60 22
1.0 0.010 0.2 5 60 22
1.0 0.005 0.1 5 60 22
1.0 0.005 0.1 5 90 52
0.027 0.005 0.1 5 50-80 50-80
1.0 0.005 0.2 5 75 37
1.0 0.005 0.1 5 80 42

If the scattering layer is placed too low, $Z < 20$ km, then atmospheric extinction reduces the predicted intensity below the observations for large solar depression angles, i.e., large values of μ_0^2. Mariner 9 television pictures (Masursky *et al.*, 1972) of Mars obtained during the dust storm also place the scattering layer at about 20 km above slant optical depth one. Thus, the Mariner 9 ultraviolet spectrometer data of the terminator during the dust storm is consistent with these results with $Z = 20$ km, $\tau_L = 0.005$, $\tau = 1$, $h = 5$ km, and $\omega_0 = 0.1$. The vanishing of the scattering layer over the north polar cap, which is shown in the Mariner 9 television pictures (Leovy *et al.*, 1972) is also evident in the ultraviolet spectrometer observations.

Since the tangent extinction optical path, τM, is greater than one, it is not possible to place the absolute altitude of the scattering layer on the basis of these data alone. A coordinated Mariner 9 experiment using combined data from the radio occultation experiment (Kliore *et al.*, 1972), the television experiment (Masursky *et al.*, 1972), and the ultraviolet spectrometer experiment place the altitude of the scattering layer at 70 km. The procedure was to use the altitude of maximum ionospheric electron density as an absolute altitude reference. This altitude was determined accurately by the radio occultation experiment and was also seen by the ultraviolet spectrometer as the region of maximum ionospheric ultraviolet emission. Since the ultraviolet spectrometer was bore-sighted with the Mariner television cameras, an absolute altitude could be assigned to the limb haze or scattering layer seen in a limb television picture. Fixing the scattering layer at an altitude of 70 km, a quantitative estimate of the extinction optical depth of the atmosphere can be made. The optical depths and revolution number are listed in Table 1.

TABLE 1

Vertical extinction optical depth of the Martian atmosphere as a function of revolution, assuming constant scattering layer altitude.

Revolution	τ
34	2.0
60	1.5
72	0.5
120	0.2
150	0.1
166	0.1

DATA

A summary of results for the time period from November 13, 1971, to February 12, 1972, will be given here. It is convenient to express the time of observation in terms of the spacecraft orbit or revolution number. Mariner 9 orbited Mars two times per day and the results reported here are from the even revolutions when nearly all of the twilight data were obtained. Revolution 2 data were obtained on November 13, 1971, and Revolution 182 data on February 12, 1972. The latitudes and longitudes of the terminator observations as a function of revolution are indicated in Figure 5. Ninety per cent of the afternoon terminator crossings have $\psi = 98° \pm 2°$, and μ is generally 0.85 ± 0.15.

At the terminator, the reflectivity is controlled by the effective single scattering albedo, ϖ_0. During the dust storm, the slant optical path, τM, was much greater than unity and even in the later revolutions up to 216, $\tau M \gtrsim 1.5$. Under these conditions where τM is large and 3050 Å radiation does not reach the surface, equation 1 may be solved for the single scattering albedo, giving

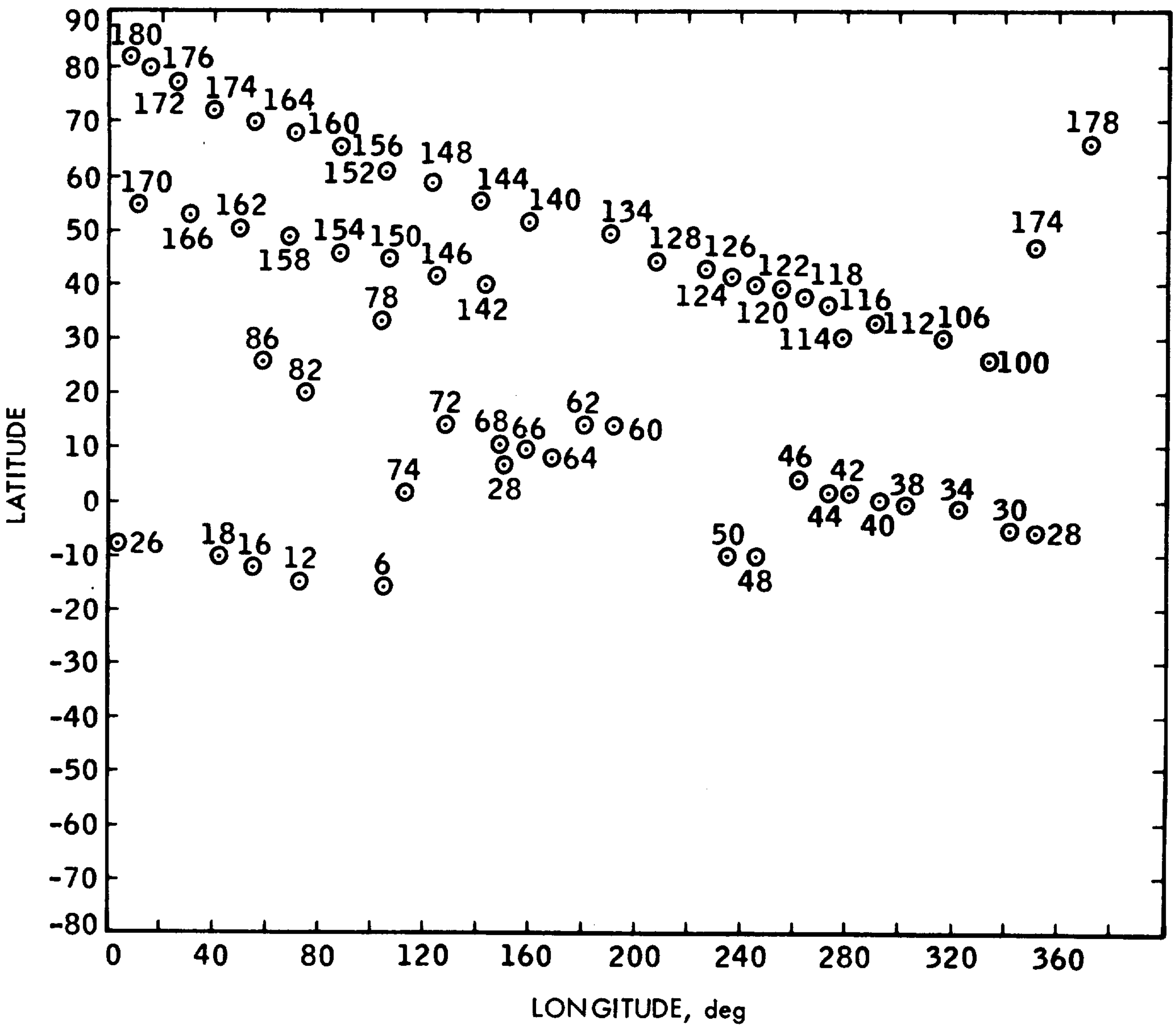
$$\varpi_0 = \frac{4\mu MR}{p(\psi)} \tag{3}$$

In figures 6 and 7, ϖ_0 is plotted as a function of revolution and latitude assuming a Rayleigh phase function. The effective albedo increased slowly until about Rev 130, when the observations passed into the polar hood region and there was a large increase in signal. The change is associated with either a waning of the dust storm in time or/and a latitudinal effect indicating clearer air in the north. The effective albedo is physically meaningful only for a homogeneous atmosphere.

Figures 8 through 17 show detailed modeling of individual terminator crossings. The individual twilight observations subdivide into distinctive time periods on the basis of brightness at the terminator and apparent scale height.

Measurements made from November 15, 1971, to December 15, 1971, revolutions 6 to 64, are very similar in shape and intensity. These terminator crossings occured at latitudes of -20° and +10° and were during the height of the dust storm. The shape of the reflectiviety curve as a func-

Figure 5 Latitudes and longitudes of afternoon terminator observations.



LATITUDE
LONGITUDE, deg
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
40
80
120
160
200
240
280
320
360
180
176
172
174
164
160
156
148
152
178
170
144
140
134
162
166
154
150
158
146
128
126
122
118
124
116
120
142
78
112
106
114
86
100
82
72
62
68
66
60
64
46
74
42
28
38
34
44
40
30
26
18
16
12
6
50
28
48

Figure 6 Effective single scattering albedo, ϖ_0, as a function of orbital revolution. Revolution 2 corresponds in time to November 13, 1971; revolution 182 corresponds to February 12, 1972.

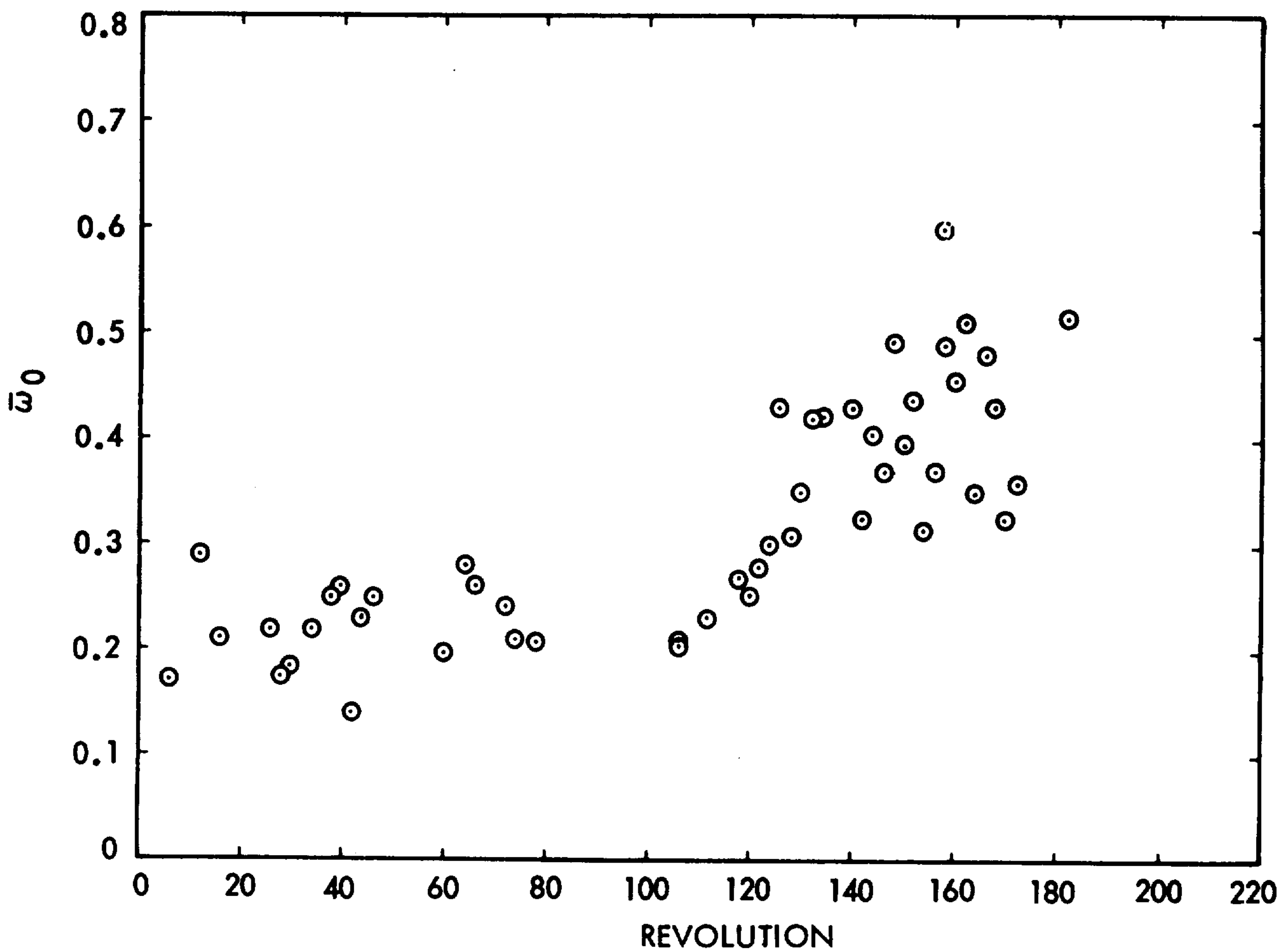
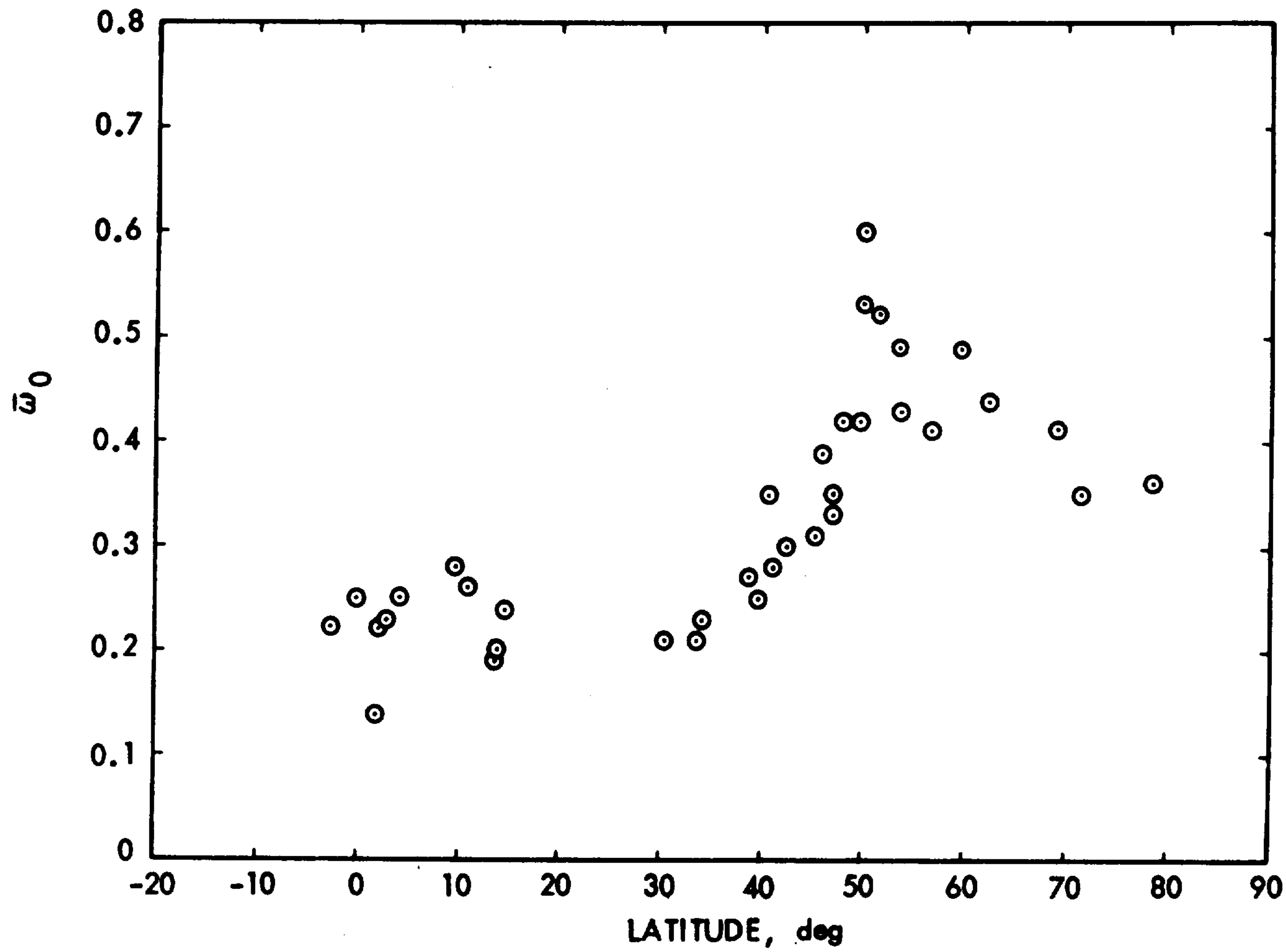

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$\bar{\omega}_0$
0
20
40
60
80
100
120
140
160
180
200
220
REVOLUTION

Figure 7 Effective single scattering albedo, ϖ_0, as a function of latitude.

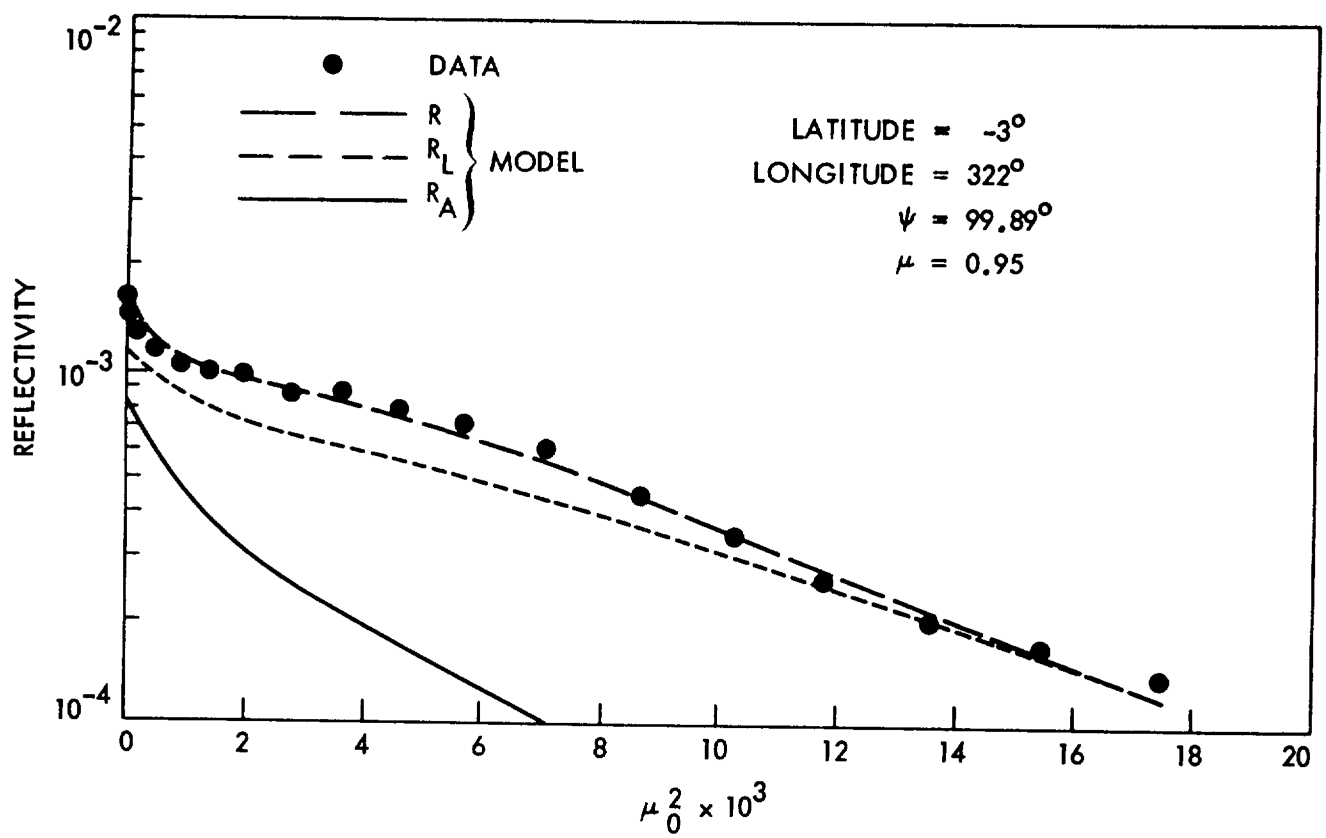


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$\bar{\omega}_0$
-20
-10
0
10
20
30
40
50
60
70
80
90
LATITUDE, deg

tion of $\mu_0{}^2$ indicates the predominant part of the signal is due to scattering from an optically thin haze of scattering optical depth 0.005 at an altitude 60 - 90 km above the surface. The effect of the dust storm is apparent for $\mu_0{}^2 > 0.01$ as the lower atmosphere begins to occult the scattering layer. The effect is diminution in the amount of solar flux reaching the scattering layer and a corresponding decrease in the reflected signal. This effect depends on the scale height of the absorbing species in the atmosphere and indicates dust was uniformly mixed with the molecular atmosphere, since the measured scale height is 9 ± 1 km. Assuming a homogeneous atmosphere, the effective single scattering albedo at the terminator is 0.2. About half of the reflectivity may be ascribed to the scattering layer. For large $\mu_0{}^2$, $\mu_0{}^2 > 0.10$, all the signal may be attributed to the scattering layer.

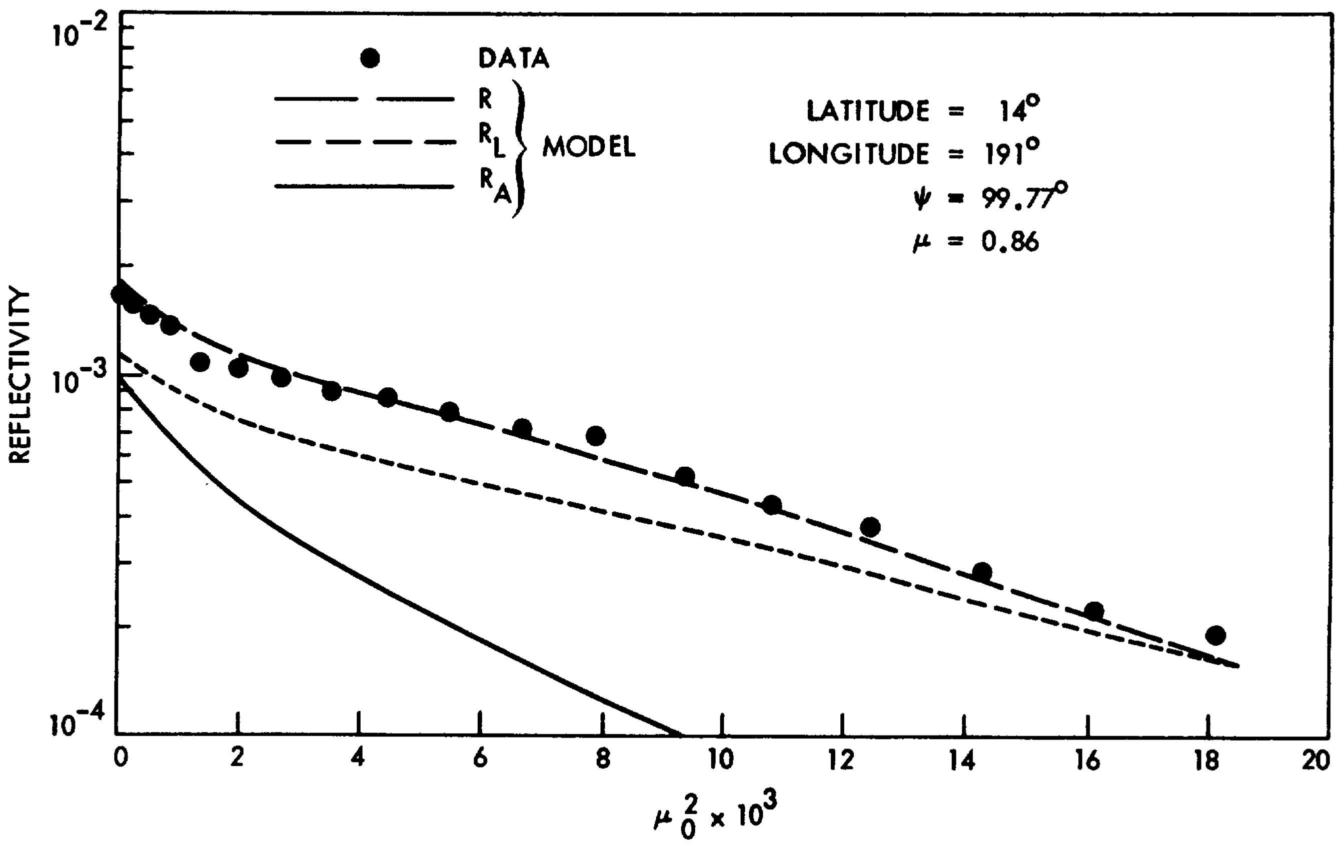
Two typical terminator observations are shown in Figures 8 and 9 which are revolutions 34 and 60, respectively. Revolution 34 data indicate a value for ϖ_0 of 0.08. The layer is about 20 km above the level where the slant optical depth is one.

Figure 8 Terminator observation on revolution 34 with the model: $\tau_L = 0.005$, $\varpi_0 = 0.08$, $h = 3.5$ km, $H = 9.5$ km, $Z = 20$ km. The lower atmosphere component is indicated by R_A; the scattering layer contribution is indicated by R_L. Combining these two components gives the composite model R. The effect of the lower atmosphere upon the scattering layer signal by absorption has been considered. Effectively, the illumination of the scattering layer at large solar depression angles is reduced by lower atmosphere absorption. The reduction in illumination of the lower atmosphere by the scattering layer is negligible. A reduction in the illumination of the scattering layer by its own absorption is sizable for small solar depression angles and has been considered.



DATA
R
R_L
R_A
MODEL
LATITUDE = -3°
LONGITUDE = 322°
ψ = 99.89°
μ = 0.95
REFLECTIVITY
10^-2
10^-3
10^-4
0
2
4
6
8
10
12
14
16
18
20
μ_0^2 × 10^3

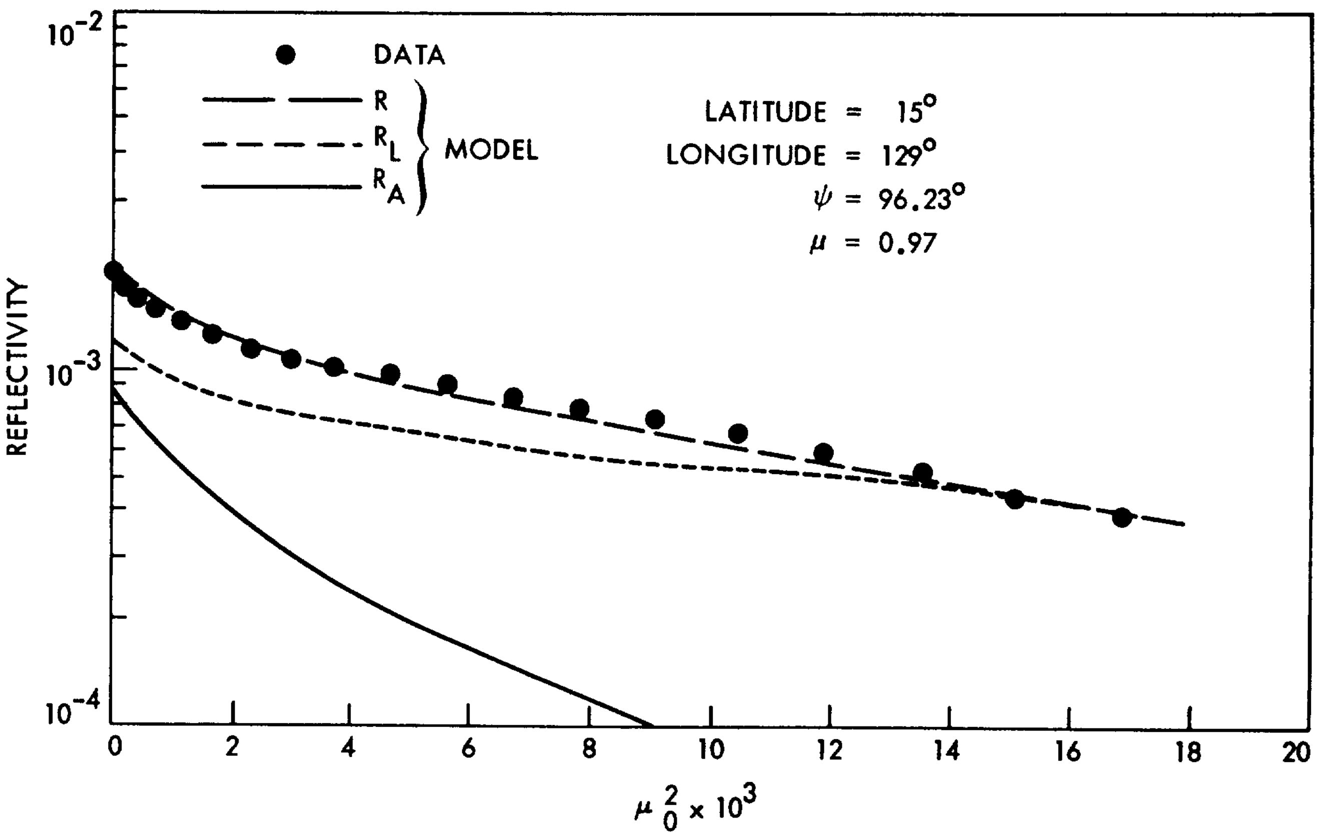
Figure 9 Terminator observation on revolution 60 with the following model: $\tau_L = 0.005$, $\varpi_0 = 0.08$, $h = 3$ km, $H = 10$ km, $Z = 25$ km.


DATA
R
R_L
R_A
MODEL
LATITUDE = 14°
LONGITUDE = 191°
ψ = 99.77°
μ = 0.86
REFLECTIVITY
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
10
12
14
16
18
20
$\mu_0^2 \times 10^3$

Data obtained for revolutions 66 to 126 covered the time period from December 16, 1971, to January 15, 1972. These terminator observations occur in the 10° N to 40° N region. For values of $\mu_0^2 > 0.01$, the apparent scale height is very large, $H \approx 20$ km. The interpretation of this result is that the dust storm is diminishing in intensity and the total vertical absorption optical depth is decreasing. The absorption of the solar radiation by the lower atmosphere is minimal up to the largest depression angles observed by Mariner 9. Thus, the scattering from the layer is essentially independent of the homogeneous atmosphere. Two typical terminator observations during this period are revolutions 72 and 120. They are shown in Figures 10 and 11. Note the apparent scale height of the signal for large μ_0^2 has increased from the previous period.

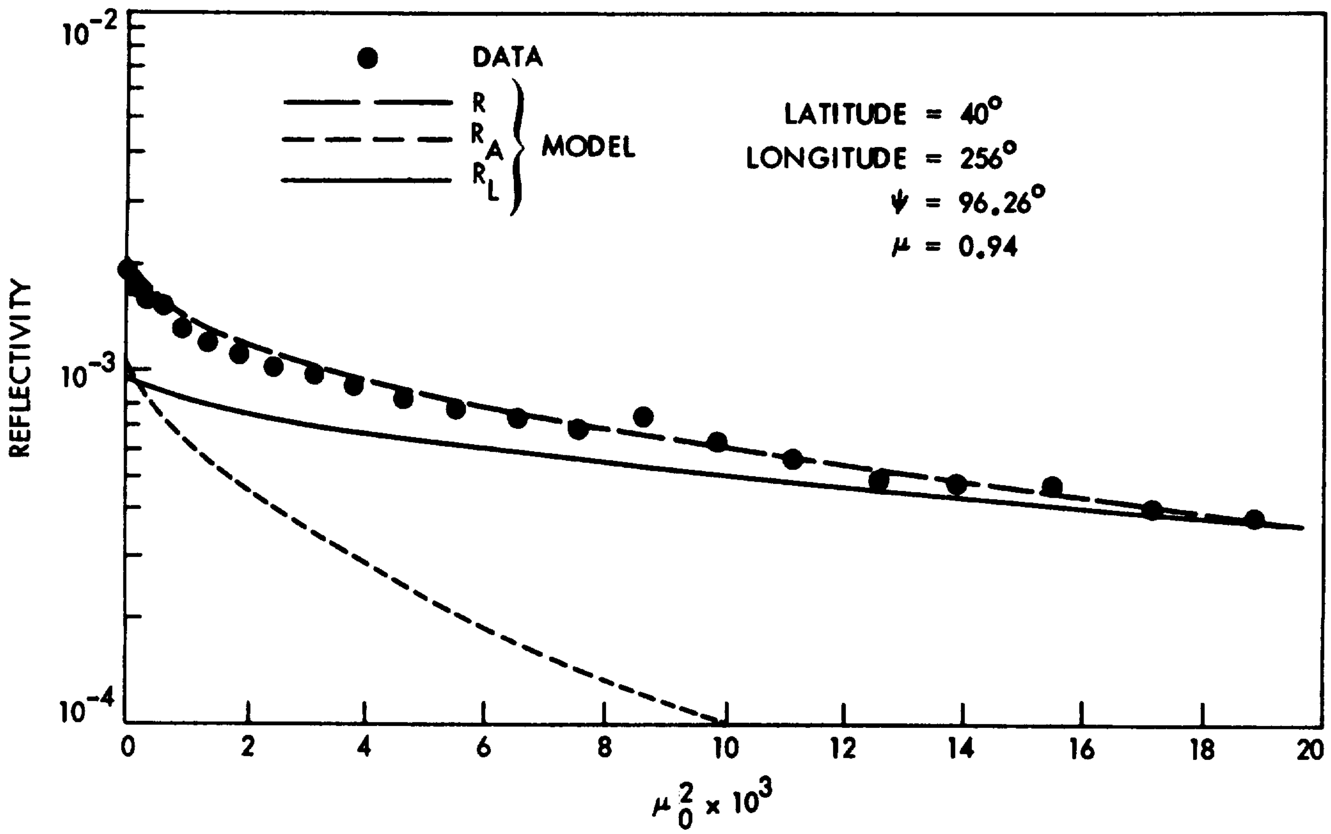
Data obtained for revolutions 128 to 146 covered the time period from January 16, 1972, to January 25, 1972. For these revolutions, the point of terminator crossing is at the edge of the north polar hood. This region serves as a transition zone. The dust storm is subsiding, and the intensity of the scattering from the layer is less. The edge of the haze layer is in the 50° ± 5° region.

Figure 10 Terminator observation on revolution 72 with the following model: $\tau_L = 0.005$, $\varpi_o = 0.08$, h = 3 km, H = 10 km, Z = 39 km.



DATA
R
R_L
R_A
MODEL
LATITUDE = 15°
LONGITUDE = 129°
ψ = 96.23°
μ = 0.97
REFLECTIVITY
10^-2
10^-3
10^-4
0
2
4
6
8
10
12
14
16
18
20
μ 2 0 × 10^3

Figure 11 Terminator observation on revolution 120 with the following model: $\tau_L = 0.004$, $\varpi_o = 0.009$, $h = 4$ km, $H = 10$ km, $Z = 48$ km.



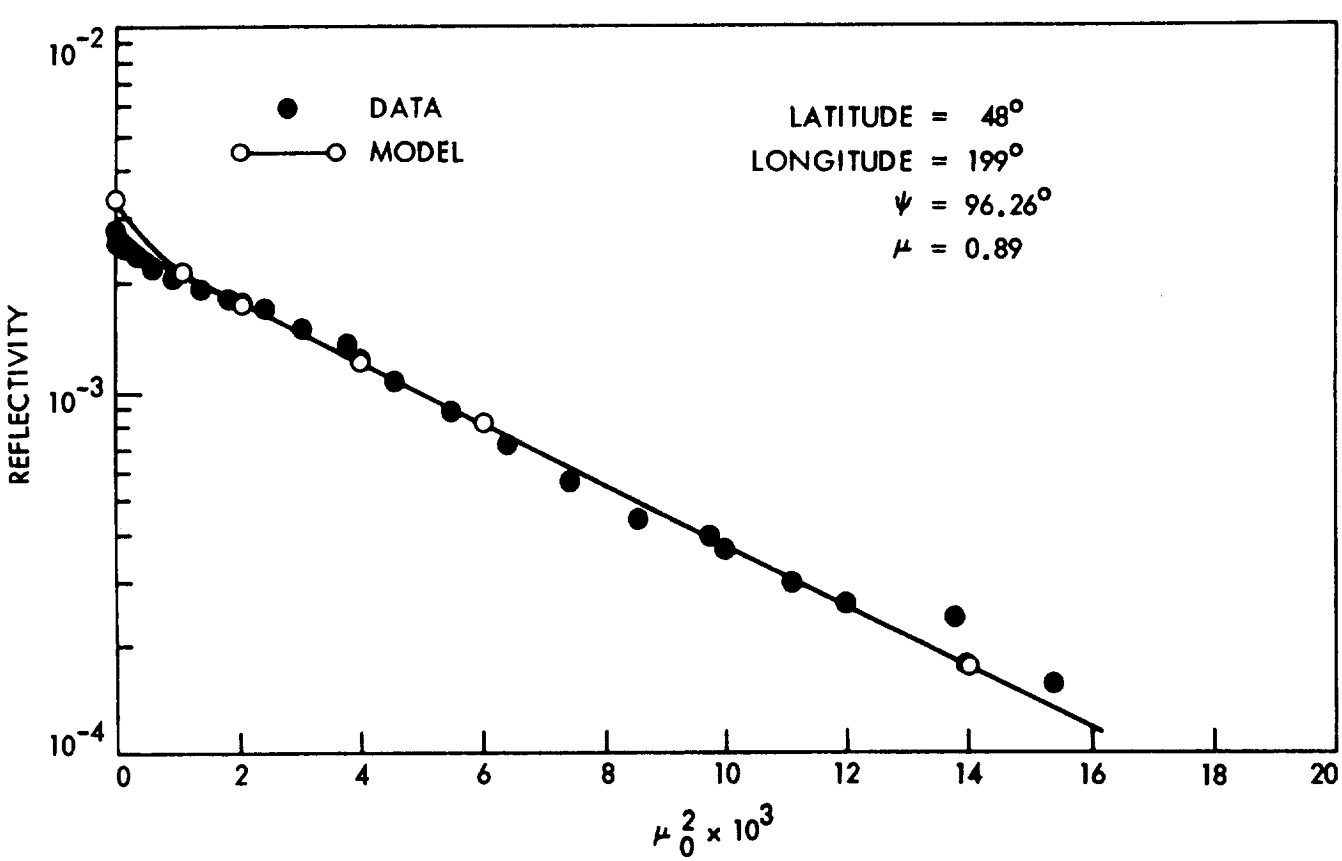
DATA
R
R_A
R_L
MODEL
LATITUDE = 40°
LONGITUDE = 256°
ψ = 96.26°
μ = 0.94
REFLECTIVITY
10^{-2}
10^{-3}
10^{-4}
0 2 4 6 8 10 12 14 16 18 20
$\mu_0^2 \times 10^3$

For these revolutions, the point of terminator crossing was moving northward, and the measured scale heights were 9 ± 1 km.

The albedo for single scattering has increased to a value of about 0.4. Plotted in Figure 12 and Figure 13 are data from revolutions 132 and 140. Two possible homogeneous atmosphere model fits to the data are presented in the data. The shape of the terminator observation is independent of extinction optical depth for $\tau > 0.1$.

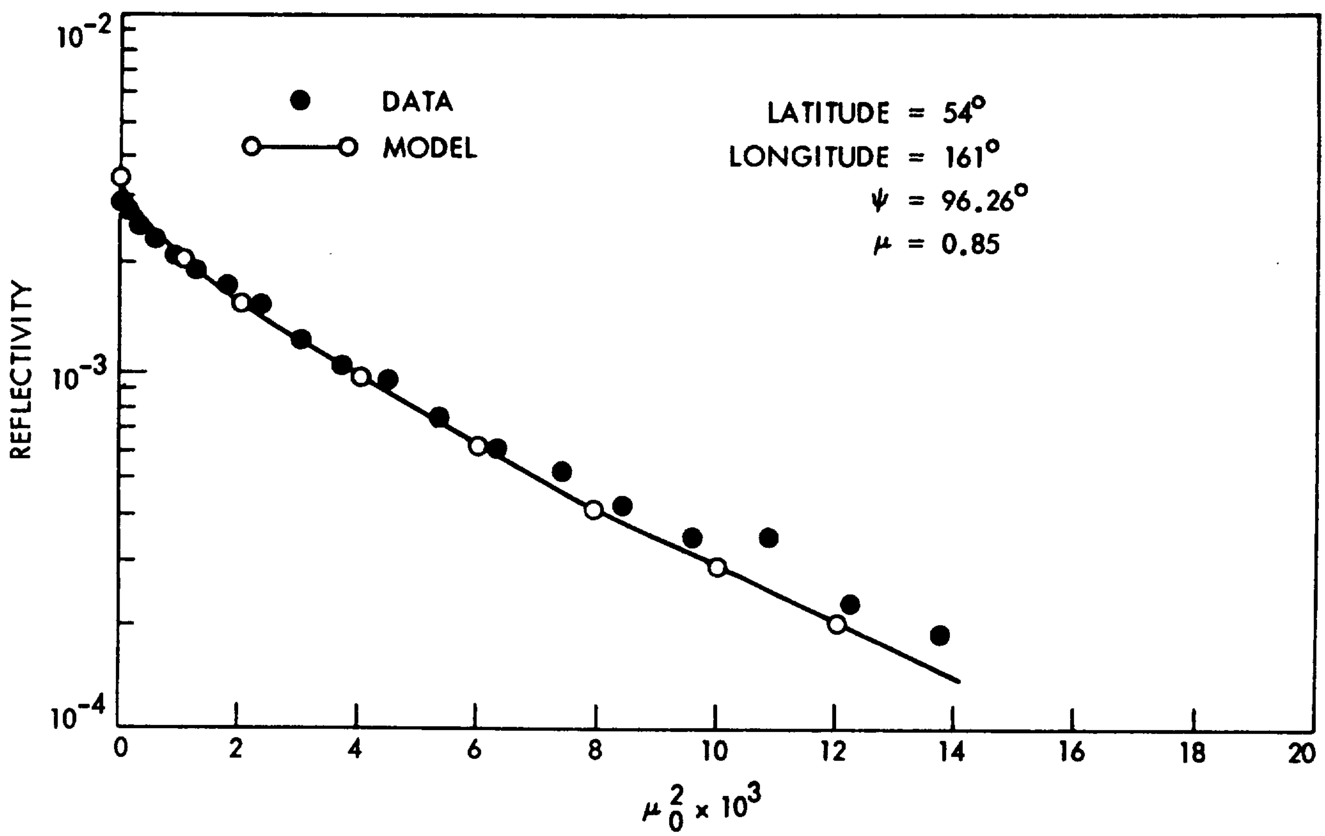
Data from revolutions 148 to 182 were obtained for the time period from January 2, 1972, to February 12, 1972. Figure 14 and Figure 15, revolutions 150 and 166, respectively, were terminator observations south of 50° N and indicate the continued presence of a scattering layer. They also indicate a clearer atmosphere as is denoted by the increasing value of ϖ_0. Figures 16 and 17 show two observations of the twilight during this time period which were taken north of the polar hood. Observations during this period can be modeled with a homogeneous atmosphere having a 6 to 8 km scale height, an albedo for single scattering in the limits $0.3 < \varpi_0 < 0.5$, and an extinction optical depth in the limits $0.05 < \tau < 0.15$. From the shape of the reflectivity vs. $\mu_0{}^2$

Figure 12 Terminator observation on revolution 132 with the following models: (I) $\tau = 0.027$, $\varpi_0 = 0.73$, $H = 9$ km; (II) $\tau \geq 0.1$, $\varpi_0 = 0.42$, $H = 10$ km. The two models nearly coincide except for $\mu_0^2 < 10^{-3}$.



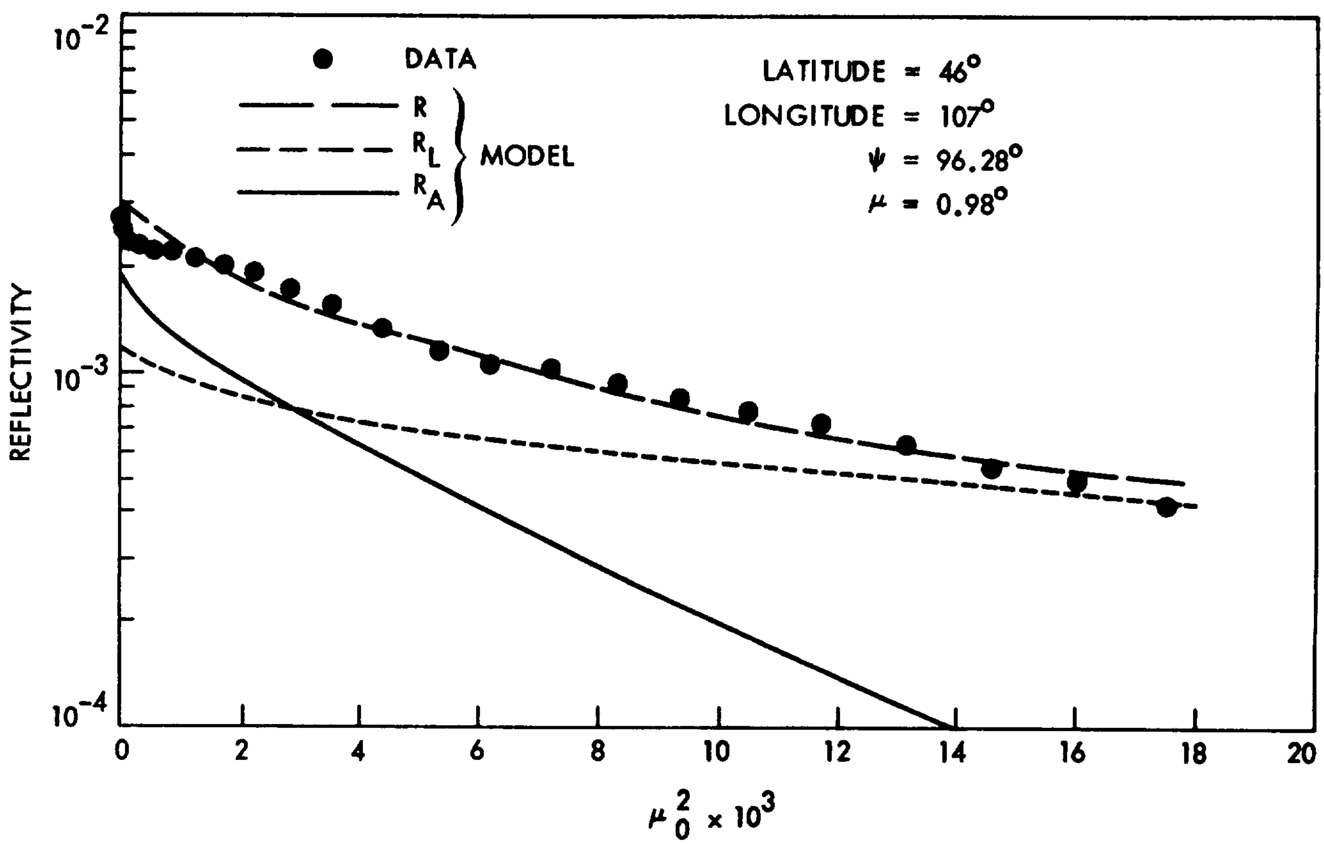
DATA
MODEL
LATITUDE = 48°
LONGITUDE = 199°
ψ = 96.26°
μ = 0.89
REFLECTIVITY
10^-2
10^-3
10^-4
0
2
4
6
8
10
12
14
16
18
20
μ_0^2 × 10^3

Figure 13 Terminator observation on revolution 140 with the following models: (I) $\tau = 0.027$, $\varpi_0 = 0.73$, $H = 8.5$ km; (II) $\tau \geq 0.1$, $\varpi_0 = 0.43$, $H = 9.0$ km The two models nearly coincide.



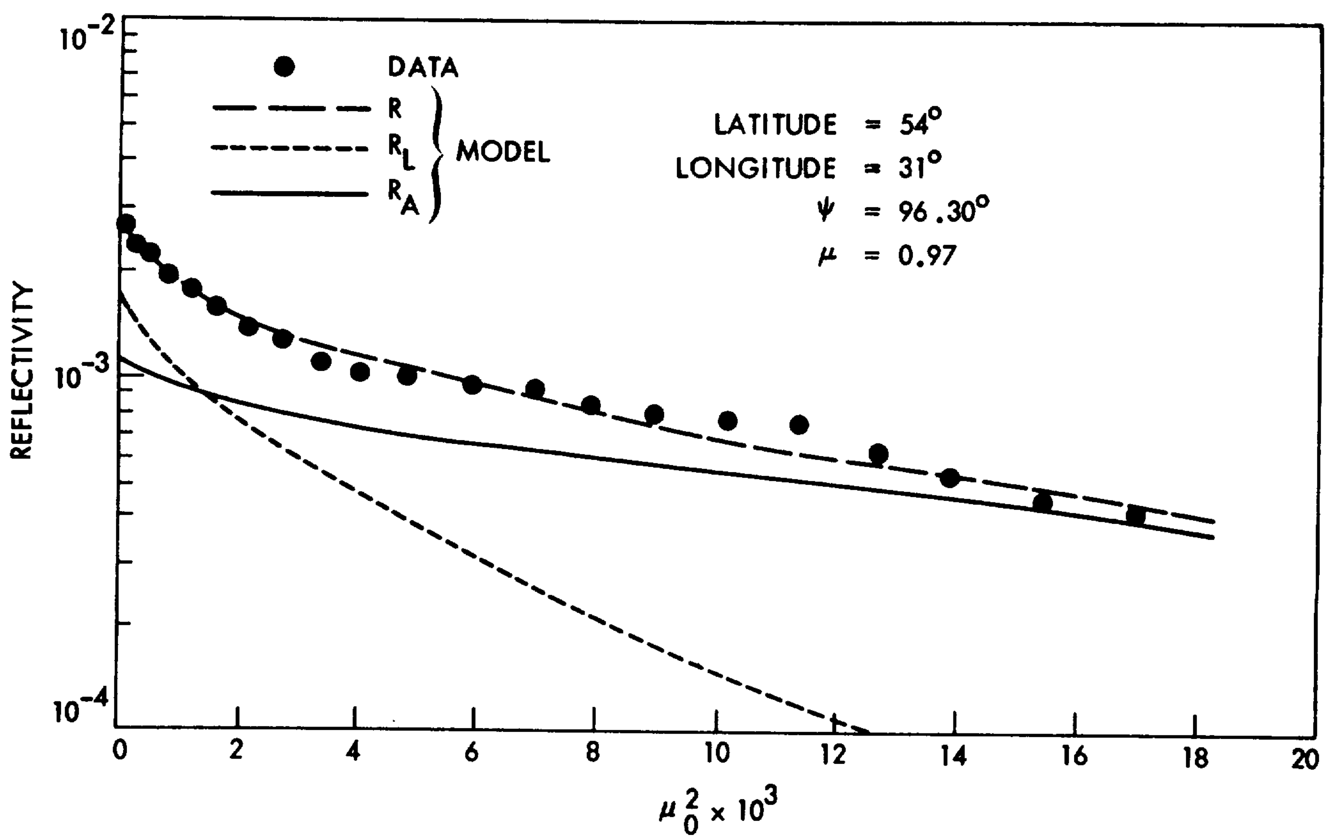
DATA
MODEL
LATITUDE = 54°
LONGITUDE = 161°
ψ = 96.26°
μ = 0.85
REFLECTIVITY
10^-2
10^-3
10^-4
0 2 4 6 8 10 12 14 16 18 20
μ_0^2 × 10^3

Figure 14 Terminator observation on revolution 150 with the model: $\tau_L = 0.005$, $\varpi_0 = 0.2$, $h = 4.5$ km, $H = 10$ km, $Z = 55$ km.



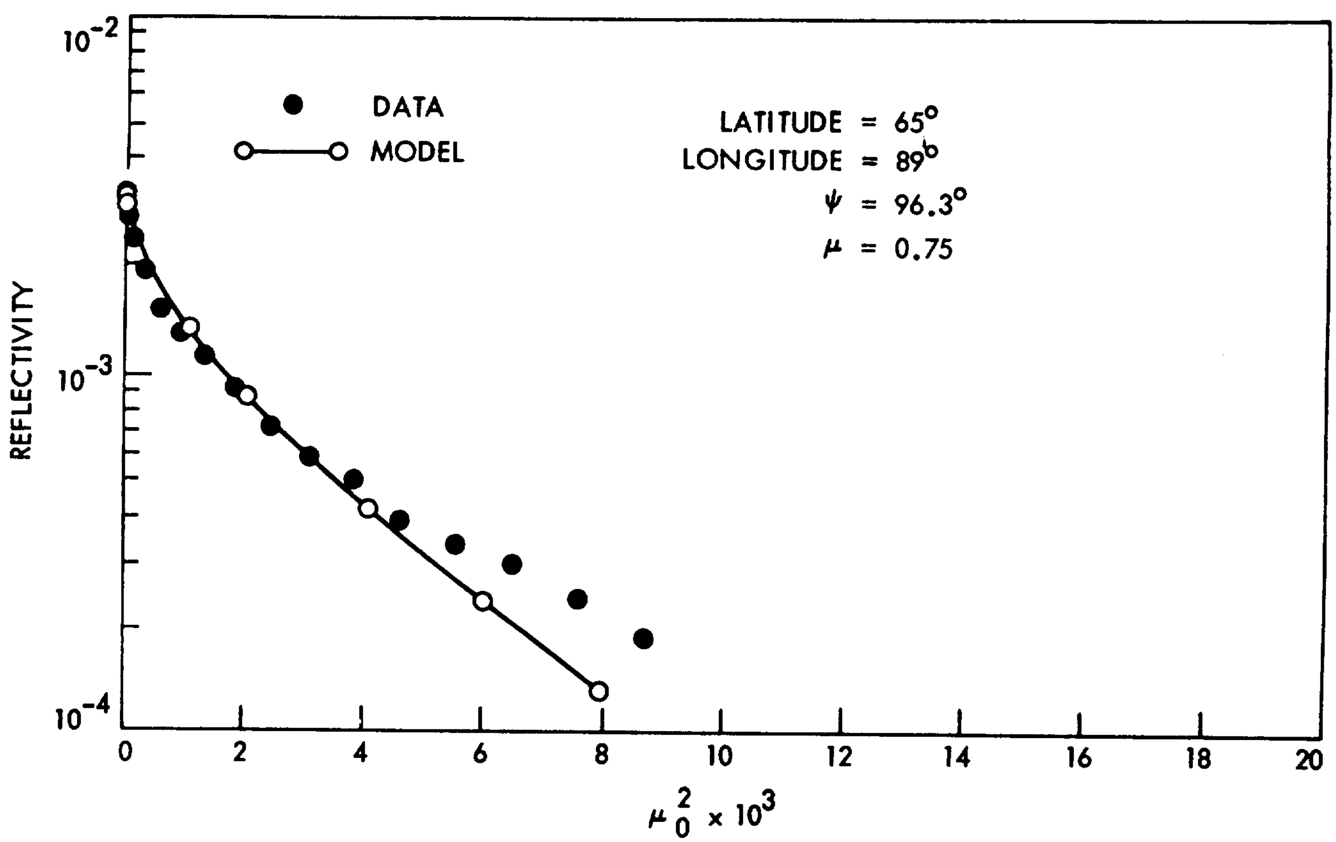
DATA
R
R_L
R_A
MODEL
LATITUDE = 46°
LONGITUDE = 107°
ψ = 96.28°
μ = 0.98°
REFLECTIVITY
10^-2
10^-3
10^-4
0
2
4
6
8
10
12
14
16
18
20
μ_0^2 × 10^3

Figure 15 Terminator observation on revolution 166 with the model: $\tau_L = 0.005$, $\varpi_o = 0.16$, $h = 4$km, $H = 10$ km, $Z = 55$ km.



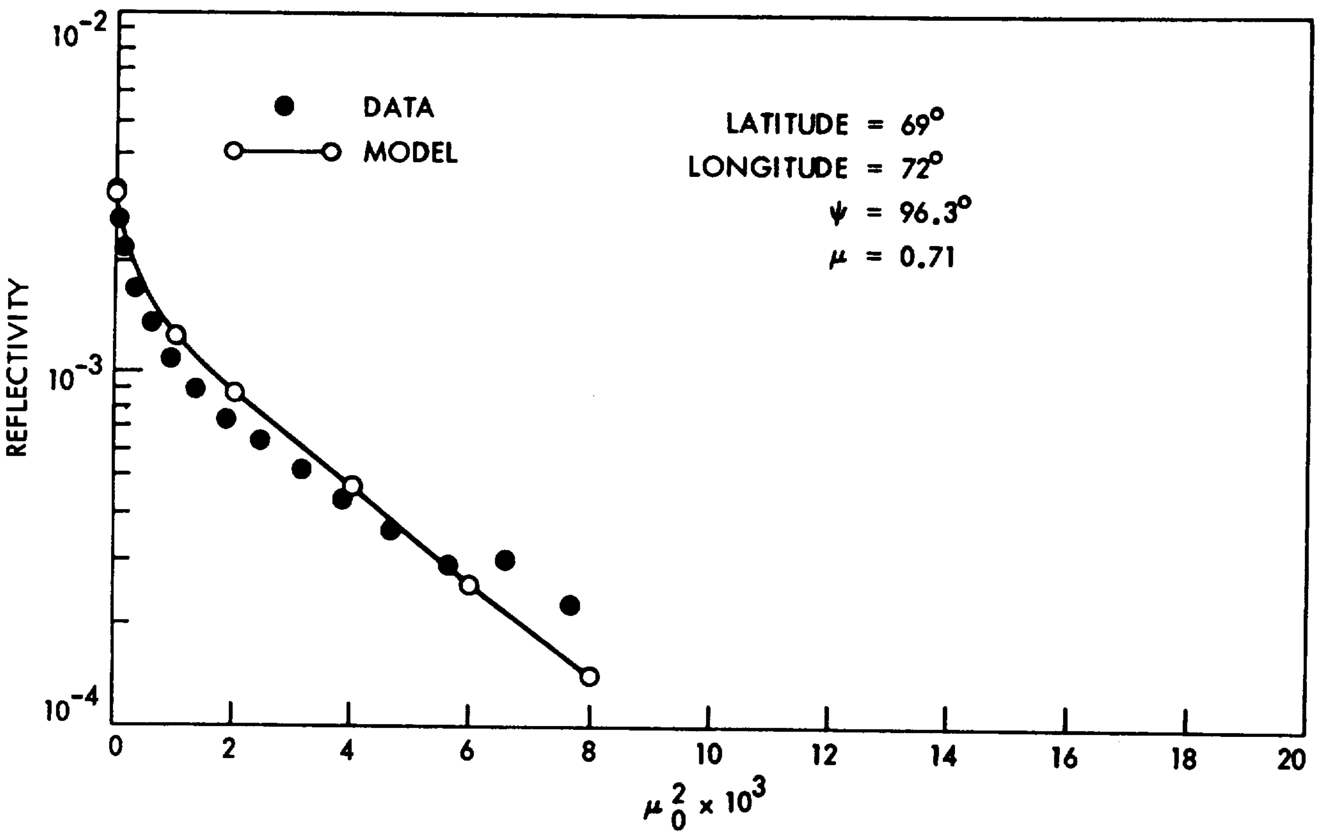
DATA
R
R_L
R_A
MODEL
LATITUDE = 54°
LONGITUDE = 31°
ψ = 96.30°
μ = 0.97
REFLECTIVITY
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
10
12
14
16
18
20
$\mu_0^2 \times 10^3$

Figure 16 Terminator observation on revolution 156 with the model: $\tau \geq 0.1$, $\varpi_0 = 0.4$, H = 6 km.



DATA
MODEL
LATITUDE = 65°
LONGITUDE = 89°
ψ = 96.3°
μ = 0.75
REFLECTIVITY
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
10
12
14
16
18
20
$\mu_0^2 \times 10^3$

Figure 17 Terminator observation on revolution 160 with the model: $\tau \geq 0.1$, $\varpi_0 = 0.36$, H = 6 km.



DATA
MODEL
LATITUDE = 69°
LONGITUDE = 72°
ψ = 96.3°
μ = 0.71
REFLECTIVITY
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
10
12
14
16
18
20
$\mu_0^2 \times 10^3$

curve for the terminator observations northward of 55° N, there is no indication of the presence of a scattering layer.

SUMMARY

It is possible to model the ultraviolet terminator observations of Mariner 9 either with a homogeneous atmosphere or with a scattering layer in addition to a homogeneous atmosphere. The characteristic shape of the twilight intensity variation is dependent on the latitude of observation. Observations north of 55° N require a homogeneous model. Twilight measurements south of 55° N indicate that a scattering layer may be a general Martian occurrence, at least in the evening. The day-to-day surveillance of the Martian terminator during the first 216 Mariner 9 revolutions indicates haze formation in the evening, and its continued presence until early morning is a daily occurrence in mid-latitudes up to 50° N.

The formation of hazes, scattering layers, or condensate clouds in the Martian atmosphere is not a new concept. Some of these layers have been variously identified as the blue clouds or violet haze (Capen, 1966; Dolfus, 1961; Slipher, 1937; Humason, 1961; Gifford, 1964; Pollack and Sagan, 1967; and Opik, 1960). Detached haze layers at the terminator were observed by the Mariner 9 television cameras (Masursky *et al.*, 1972).

Clouds of water crystals are the probable scatterers which explain the large apparent scale height in Martian twilight at 3050 Å.

During the dust storm, the profiles of reflectivity as a function of $\mu_o{}^2$ indicated a vertical extinction opacity of 1 to 2, a single scattering albedo of about 0.08, and a scale height of 9 ± 1 km. By revolution 130, January 17, 1972, the atmosphere showed marked clearing either because of a waning of the dust storm or because of clearer atmosphere at northern latitudes. By revolution 180, February 10, 1972, the albedo for single scattering had values between 0.3 and 0.5, indicating the continued presence of absorbing dust in the atmosphere. The vertical extinction optical depth at that time was 0.1 ± 0.05 which is about three times the clear atmosphere value.

ACKNOWLEDGMENTS

The authors thank David Rusch, Donald Anderson, Douglas Strickland, Conway Leovy, Gary Thomas and Kevin Pang for stimulating discussions. We also thank Karen Simmons for making the computer plots.

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